Soil Science for Archeologists

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In December 1999, the Southeast Archeological Center (SEAC) of the National Park Service and the Agricultural Department of Florida Agricultural and Mechanical University (FAMU) in Tallahassee entered into an agreement to develop a workshop to train archeologists in soil classification. The goal was to acquaint the archeologists with soils typically found at archeological sites in the region.

FAMU agronomist, Dr. Stewart Reed, conducted the two-day class. Two sites were visited: the Spanish Mission San Luis located on the red clay hills of Tallahassee, and a small, multicomponent prehistoric shell midden (8Wa29) on the sandy Gulf of Mexico shoreline south of Tallahassee. Open archeological units were examined at both sites. Methods for determining horizonization, particle size, compaction, moisture content, clay content, texture, and color were described and practiced by the participants.

The class will be offered annually to students and archeologists. This manual was written for the participants and will be updated periodically. It is the first of two volumes, the second of which is forthcoming and will feature case studies from class projects. For more information, please contact Mike Russo at SEAC: 850-580-3011, ext. 238, or mike_russo@nps.gov.

WHAT IS A SOIL?

Soil, in terms of its morphological characteristics, is defined as unconsolidated surface material forming "natural bodies" made up of mineral and organic materials and the living matter within them. Soil is a dynamic entity with material continually and simultaneously added, removed, and transformed. Its formation begins with a parent material derived from either the underlying rock or material transported from somewhere else to its present site.

It is mainly the combined effects of climate and living matter that convert a material to a soil. For example, in temperate rainy environments, moisture and dense vegetation may lead to deep, richly organic soils. In deserts, with the lack of moisture and subsequent vegetation, soils may be thin and remain highly mineral. Human disturbances, such as dwellings, agricultural practices, grave sites, and garbage dumps, may also affect soils, giving them other unique characteristics.

This manual reviews the basic genesis, morphology, and physical, chemical, and mineralogical properties of soil. With careful observation of these properties, archeologists can often identify previous human impacts on sites and gain additional data to help determine the activities that led to the present soil characteristics.

CONSTITUENTS OF SOIL

Soil material has four basic constituents: mineral or inorganic matter, organic substances, water, and air.

MINERAL MATTER

Mineral or inorganic matter can be crystalline or amorphous. A crystal is a chemical compound with a definite chemical formula and a distinct molecular structure. For example, the mineral gibbsite has the chemical formula $Al(OH)_3$. The small Al^{3+} ion is in the center, surrounded by three hydroxyls (OH) that are equidistant apart. Hydrogen ions can be removed, opening bonds. This allows the crystal to grow laterally and vertically forming sheets that stack up like a deck of cards.

Amorphous minerals lack a repeating long-range structure, but often atoms appear in a definite ratio. A charge may be associated with the surface of mineral matter. Predominantly negative, the charge can also be positive. The type and amount of charge give minerals certain characteristic properties, such as shrink/swell potential and nutrient retention.

ORGANIC SUBSTANCES

Organic substances are molecules with carbon-to-carbon bonds. In soils, these molecules are formed by biochemical activity. Animals, insects, and soil microorganisms act together to decompose dead plant leaves, root tissue, and animal remains in the soil. Organic matter in soils ranges from leaf litter, where decomposition is minimal and plant species are still recognizable, to a highly decomposed substance called humus, which gives soils a dark brown color.

Organic matter tends to accumulate near the surface where high biological activity, such as leaf litter, roots, and insect life, occurs. As a result, soils near the surface are normally darker in color than the soil horizons a few centimeters below. Organic matter provides a reserve source of plant nutrients and buffers soil against pH changes. It forms a very weak cement that, when acting alone, binds soil particles together in a crumb-like structure.

Living organisms residing within the matrix are considered part of the soil. Different fungi, bacteria, protozoa, algae, and actinomycetes play a vital role in converting parent material into soil. Plant roots, rodents, worms, insects, and other burrowing creatures help redistribute matter within a soil profile.

WATER

Soil pores provide an important reservoir for water and atmospheric gases. Soil water is the medium through which nutrients are transferred to plants. Since water has a great capacity to adsorb heat, it can insulate soil from rapid temperature changes. A moist soil is slower to heat in the spring and slower to freeze as the temperature drops.

Hydrogen ions from both organic and inorganic matter dissociate in water, resulting in the soil's pH. A soil's pH affects the solubility of minerals. Soil water may be lost in several ways:

- as transpiration from plant leaves;
- through evaporation from the soil surface;
- by draining through soil pores to groundwater reservoirs;
- through lateral flow; and
- by being held in relatively small pores.

The maximum amount of water a soil holds against gravity is its field capacity. A soil's field capacity is a function of the volume of pores small enough to hold water against gravity. The process is similar to that of a sponge holding water.

AIR

Pore space not filled with water contains gases in concentrations comparable to those in the atmosphere. The soil air is the source of oxygen for root and microbial respiration. A high respiration rate,

coupled with the twisting path that a gas must follow in order to diffuse out of soil pores, results in a carbon dioxide concentration about one hundred times greater than that in the atmosphere. Individual gasses move into and out of soil pores primarily by diffusion. After a heavy rain, soil pores fill with water displacing the air.

Oxygen diffuses very slowly through water. Therefore, once a soil becomes saturated with water, respiration quickly removes oxygen from the pores. If the soil layer remains wet for significant periods during the year, the low oxygen content will result in a change in the oxidation/reduction state. Soils so affected become increasingly reduced. Iron oxide minerals in this environment of reduction will change color from red/yellow to a light gray. This change in color can be indicative of a seasonal high-water table.

SOIL FORMATION

The five soil forming factors are: parent material, topography, climate, biological activity, and time.

Soil formation begins with a parent material derived from weathering of either the native rock or material transported to the site. The concerted effect of climate and biological activity then transforms parent material by producing the physical and chemical energy to alter minerals and vertically redistribute material through the soil profile. The effect of climate and biological activity is modified by topography. For example, slope affects the amount of water flowing down through the profile as opposed to running off the surface. Finally, soil forming processes work slowly over time. The intensity and direction of these processes can also change over time. During any given period, one process may dominate; but, with time, another process can become dominant.

PARENT MATERIAL

Parent material is the initial mineral substance that forms a soil. It may reside at the site of its origin or be transported from somewhere else to its current location. A soil formed from parent material found at the site of its origin is called a residual or sedentary soil. Bedrock weathering in place produces a stony, massive material called saprolite. As physical and some chemical weathering occur, the saprolite becomes more dense than the underlying bedrock. The texture and original rock structure remain, but the material is soft enough to dig with a hand shovel. As chemical weathering converts primary minerals to secondary minerals, particles are redistributed vertically. As material is both added and removed, a soil develops. A residual soil will retain many of its characteristics from underlying bedrock. Soil texture, mineralogy, pH, and other characteristics may be a direct result of the saprolite below.

Material can be eroded from one place and transported to another where it becomes parent material for a soil at the new site. Often weathering occurs before the material is transported to the new site. In this case, the soil may have few features in common with the underlying rock. Transported material can bury an existing soil at the new site. Once a depositional episode is completed, time zero for the new soil's formation begins. Several forces can supply energy for the transportation of parent material: ice, wind, water, and gravity.

Ice
Glacial deposits occur at the front and sides of advancing ice. Normally this material is poorly sorted with respect to particle size. Because ice melts from the bottom, this is also true of material deposited under a glacier. Also, material can be deposited as outwash in the glacier's meltwater.

Soils formed from glacial deposits vary in composition depending on the rock type over which the glacier traveled. Since glaciers advance and retreat with time, the composition and depositional environment of the parent material can be quite complex. Overall, the texture of soil produced in glacial deposits reflects the mode and distance of transport and the type of rock scoured. Shale and limestone scouring tends to produce a soil with relatively more clay and silt-sized material. Igneous and metamorphic rocks produce mostly sandy soils. Deposits beneath the ice usually result in finer textured, denser materials, whereas outwash and front and side deposits are generally coarser.

Wind

Wind deposits two major types of material: eolian sands and loess. Clay-sized material (< 0.002 mm) tends to bind together in aggregates too large to erode by wind.

Eolian sands are windblown deposits of material predominantly greater than 0.05 mm (0.05 to 2 mm) in diameter. Most of this material moves in a series of short-distance jumps called saltation. Eolian deposits may move several kilometers from the source. Material adhering to saltating sand particles and material deposited as an aerosol are the sources of clay in eolian sand. Normally this material has a narrow textural range and is deposited on the leeward side of valleys or bodies of water.

Loess, which is windblown silt-sized material (0.002 to 0.05 mm), once airborne, can travel several hundred kilometers before deposition. The texture of loess usually does not vary in a vertical direction, but tends to thin with horizontal distance from the source.

Windblown material tends to have sharp edges, a conchoidal shape, and surface etching. In contrast, material deposited by water tends to have rounded edges and a polished surface. Careful observation under a hand lens can shed light on the environment present at deposition.

Water

An alluvial or stream-borne deposit occurs in floodplains, fans, and deltas. Because fast-moving water picks up debris, a river meandering downstream will undercut the outer bank of each bend. Water moves slower around the inner bank than the outer bank and therefore loses energy. Thus, coarse material settles out, forming a bar over the inner bank. As water levels rise during floods, the stream overflows its channel and spills over onto the floodplain.

Typically, alluvial deposits are characteristic of the decrease in energy during deposition. Where the stream overflows its bank, the energy is still relatively high; only deposits of coarse material occur, forming a levee. On the far side of a levee, moderate energy is available, and silty material settles.

On the floodplain, water velocity and its corresponding energy is low, and clay settles. Because bars form under moderate energy, this type of sorting does not occur on the plain. However, a floodplain may surround a bar. As the distance from the channel increases, the material's texture becomes finer, and the thickness of the deposit decreases.

Alluvial fans form where water in a channel, carrying sediments downhill, experiences an abrupt reduction in slope. The stream energy is reduced quickly, and material settles. This also occurs where a narrow valley opens onto a wide flat. Fans have a cone shape, widening in the downslope direction. Channels shift easily in fan deposits, and sediments are reworked over time. The texture of a fan becomes finer with distance from its apex. Normally fans in humid areas are not as steep and cover a much larger area than those in arid regions.

Marine and lacustrine deposits form in low-energy environments under inland seas and lakes. These sediments are typically coarse near the shore and finer toward the middle of the lake or sea.

Several shoreline features can be associated with inland water bodies, including deltas, sand dunes, and beaches. Deltas are essentially alluvial fans with their sediments deposited underwater. As lakes dry, evaporite minerals form. Under other conditions, eolian sediments can fill in the lakebed. Such soils have a finer texture and occupy lower sections on the landscape. Soils formed in shoreline deposits have a coarser texture and occupy higher landscape positions. In lakebeds with a very low influx of sediments, organic substances dominate the sediments, and peats form.

Gravity

Colluvium or hillslope sediments result from the force of gravity and runoff moving downslope. This material may be deposited in catastrophic events,

such as mudslides, or by very slow but persistent processes, such as slope wash or surface creep. As viewed from the crest of a hilltop, sediments thicken, and the clay content increases on the downslope.

TOPOGRAPHY (RELIEF)

Topographic relief, or the slope and aspect of the land, has a strong influence on the distribution of soils on a landscape. Position on a slope influences the soil depth through differences in accumulation of erosional debris. Slope affects the amount of precipitation that infiltrates into soil versus that which runs off the surface. Aspect, or the direction a slope is facing, affects soil temperature. In northern hemisphere sites, south-facing slopes are warmer than those facing north. Differences in moisture and temperature regimes create microclimates that result in vegetational differences with aspect. Differences in weathering, erosion, leaching, and secondary mineral formation also can be associated with relief.

CLIMATE

Climate arguably has the greatest effect on soil formation. It not only directly affects material translocation (leaching or erosion, for example) and transformation (weathering), but also indirectly influences the type and amount of vegetation supported by a soil. Precipitation is the main force in moving clay and organic matter from the surface to a depth within the profile. When a soil is at field capacity, the addition of more water will result in drainage either downward or laterally. Drainage water carries with it dissolved and suspended clay particles that collect at a new location within the soil profile. As a result, soils often show an increase in clay with depth as wind erosion selectively removes clay (and organic matter) from surface horizons.

Temperature and moisture affect physical and chemical weathering. Diurnal and seasonal changes in temperature cause particles to expand and contract unevenly, breaking them apart. Heat and moisture are active agents of chemical weathering, the conversion of one mineral into another.

Climate affects the type and amount of vegetation in a region. A warm, humid climate produces the most vegetative growth; however, microbial decomposition is also rapid. The net effect is that tropical and subtropical soils are generally low in organic content. In contrast, organic matter tends to be highest in a cool damp environment where decomposition is slow.

Temperature and the amount of water moving through a profile affects all of the following:

- the amount and characteristics of organic matter;
- the depth at which clay accumulates;
- the type of minerals present;
- soil pH (humid climates tend to produce more acidic soil than do arid climates);
- soil color;
- iron, aluminum, and phosphorus distributions within a soil profile; and
- the depth to calcium carbonate and/or salt accumulation.

BIOLOGICAL ACTIVITY

Biological activity and climate are active forces in soil formation. Soil pedogenesis involves a variety of animals, plants, and microorganisms. Ants, earthworms, and burrowing animals, for example, mix more soil than do humans through plowing and construction. Plant roots remove mineral nutrients from subsoil and redeposit them at the surface in leaf litter. Growing roots open channels through soil where rainwater can wash clay and organic matter down along these channels. Soil microbes decompose plant and animal debris, releasing organic acids. This biochemical activity is the catalyst for a great deal of the oxidation/reduction and other chemical reactions in soil.

The distribution of organic matter in a forest soil is different from that in a grassland. The surface soils of forests tend to have concentrated organic matter, which quickly decreases with depth. Grassland soils tend to accumulate organic matter to a greater depth than do forest soils. It is important for archeologists to note that the dark staining from the humic fraction of organic matter can persist in a buried soil. Thus, ancient buried surface soils may be recognized in the field by color alone.

The distribution of iron and aluminum throughout a profile also differs between forest and grass-

land soils. In forests, due to the greater rainfall, clays and organics drain downward, leaving behind resistant minerals. As a result, iron and aluminum in B horizons in forest soils are found in higher concentrations than in grassland soils.

TIME

Soils develop over time. Soil formation is a dynamic process, where a steady state is slowly approached but only rarely reached. The rate at which a soil forms is related more to the intensity of other soil forming factors than to chronological age.

Soil development begins with a parent material that has a surface layer altered by vegetation and weathering. For example, a young Coastal Plain soil has relatively uniform material throughout, and is altered only by a dark-stained surface layer that has been formed by vegetation. A more mature soil, on the other hand, shows evidence of the removal and transport of surface-layer clay to a subsurface layer called the B horizon. In an even older soil, chemical weathering and leaching have removed silicon, causing a change in the suite of clay minerals. A senile soil is excessively weathered and dominated by very resistant iron and aluminum oxide minerals. The rate that a young Coastal Plain soil becomes a senile soil depends not on its chronological age but on how rapidly minerals are transported and transformed within the profile.

Human activity frequently alters the process of pedogenesis. Once human activity ends, soil formation can continue as before—if no radical change in the soil-forming factors occurred in the interim. Because fine material leaches selectively faster than coarse material, differences between human-altered and undisturbed soils in the ratio of fine to coarse clay may be apparent in a relatively short span of time (one hundred years in a humid environment).

WEATHERING

Weathering is the physical and chemical processes by which rocks and minerals are disintegrated, decomposed, and resynthesized into new compounds. (Here rocks refer to unconsolidated material and soil at the surface [regolith], while minerals are inorganic substances with a definite chemical structure and formula.)

Weathering encompasses both physical and biogeochemical processes, which generally occur simultaneously. At different times, however, one process may dominate. In a soil forming from saprolite, for example, physical weathering dominates initially. As more surface area is exposed with smaller particles, and as biological activity increases, chemical weathering takes over.

PHYSICAL WEATHERING

Physical weathering is the mechanical disintegration of rocks and minerals into smaller sizes. Some of the several mechanisms that work to break apart rocks include: temperature, water, ice, glaciers, erosion, wind, and plants and animals.

Temperature
Seasonal and even day-to-night temperature changes can cause rocks to heat and cool unevenly. As rocks heat up, they expand; as they cool down, they contract. The outer surface expands and contracts faster than the interior, causing the outer surface to separate and peel off.

Water

The force of raindrops beating down on soft rocks, and the scouring effect of suspended material in water flowing over rocks can wear the rocks away with time.

Ice

Water can infiltrate the cracks and pores of rocks and freeze. As the ice expands and thaws, the rocks break up.

Glaciers

Glaciers weather rocks in several ways. The weight of a glacier can crush rocks. As it moves over an area, a glacier can grind and pulverize rocks. As it recedes, the pressure release can cause rocks to expand and crack.

Erosion

Erosion causes pressure-release related weathering.

Wind

Wind suspends fine particles. As the particles are pushed and bounced over one another, they abrade the rock surfaces over which they pass, slowly wearing the rocks down. Over time, the material removed results in pressure-release weathering similar to that of retreating glaciers.
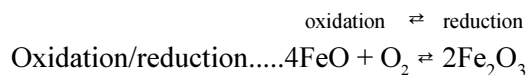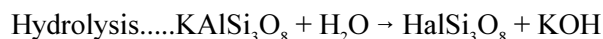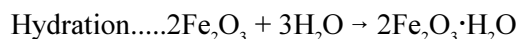
Plants and Animals

The expansion and decomposition of roots growing in soil can alter the density and coherence of particles. The digging and burrowing of animals can have the same effect.

CHEMICAL WEATHERING

The process of chemical weathering changes the atomic makeup of a mineral. Near the surface, water and biological activity play important roles in chemical weathering. Given time and enough water moving through a profile, even seemingly insoluble minerals will slowly dissolve. These minerals loose a portion of their atomic makeup and reprecipitate as new minerals in a leachate.

Water hydrates minerals, weakening them as it expands the size of their crystals. Hydrolysis removes atoms (ions) from certain minerals and, in the process, splits water molecules affecting the soil pH. Carbon dioxide mixed with water causes a form of acid hydrolysis called carbonation.

Another mechanism of chemical weathering is oxidation/reduction, or the transfer of electrons from one substance to another. Oxidation/reduction affects both the solubility and stability of minerals. Some mechanisms of chemical weathering include:

$$Solution.....CaCl_2 + H_2O \rightarrow Ca^{2+} + 2Cl^- + H_2O$$

$$Hydration.....2Fe_2O_3 + 3H_2O \rightarrow 2Fe_2O_3 \cdot H_2O$$

$$Hydrolysis.....KAlSi_3O_8 + H_2O \rightarrow HalSi_3O_8 + KOH$$

$$Carbonation.....CaCO_3 + H_2O \rightleftharpoons HCO_3^- + Ca^{2+} + H^+$$

$$\overset{oxidation \quad \rightleftharpoons \quad reduction}{Oxidation/reduction.....4FeO + O_2 \rightleftharpoons 2Fe_2O_3}$$

MINERALOGY AND WEATHERING SEQUENCES

Based on their formation, minerals are grouped into two broad classes: primary minerals and secondary minerals.

PRIMARY MINERALS

Primary minerals have not been altered chemically since the time of their crystallization from molten lava and their subsequent deposition. The Bowen reaction series chart (Figure 1) lists several primary minerals in sequence based on resistance to weathering. The lower the minerals fall on the chart, the more they resist weathering.

SECONDARY MINERALS

Secondary minerals form from the decomposition of primary minerals and a subsequent reprecipitation into a new, chemically distinct mineral. Layer alumino-silicates are the dominant minerals formed in most temperate region soils. These layer silicates are composed of various arrangements of silicon/oxygen sheets in tetrahedral coordination and aluminum/oxygen sheets in octahedral coordination.

Kaolinite is composed of one silicon/oxygen tetrahedral sheet and one aluminum/oxygen octahedral sheet and therefore is called a 1:1 mineral. Kaolinite forms in warm to hot, subhumid to humid climates. This mineral crystallizes in acid soil where basic cations (positive ions) and some silicon have been leached. Vermiculite is a 2:1 mineral with two silicon tetrahedral sheets surrounding one aluminum octahedral sheet. It forms in subhumid to humid soils high in mica. Hydrous mica (illite) forms in subhumid cool areas as mica dissolves and recrystallizes. Smectites, including montmorillonite, form in arid to humid soils with low permeability and minimal leaching. As primary minerals dissolve, leaching does not remove their constituents and they are available for recrystallization as smectites. Illites and smectites are 2:1 minerals. The mineral chlorite (2:2) forms in marine sediments exposed to weathering.
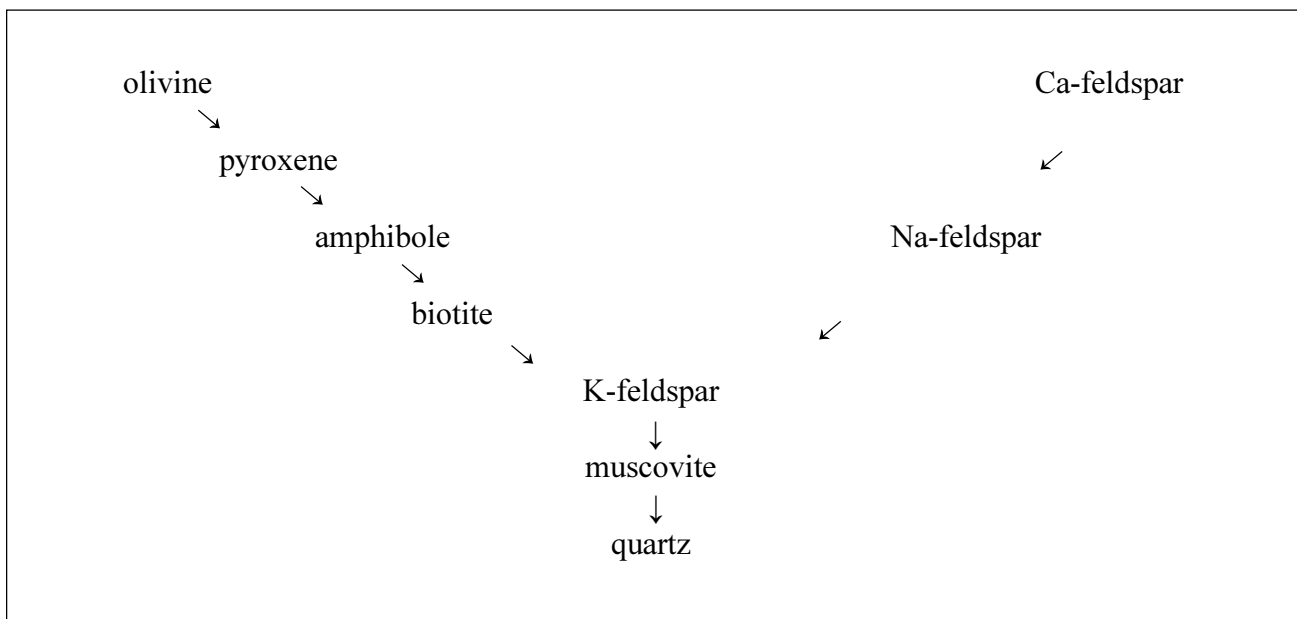

Figure 1 — Bowen reaction series.

Within a warm to hot, subhumid to humid climate, well-drained soil containing parent minerals high in magnesium fosters chlorite formation.

Iron and aluminum oxides and hydrous oxides, collectively called sesquioxides, dominate soils in the humid tropics. Sesquioxides form in hot wet regions where soils are subject to excessive weathering. High precipitation is necessary to leach silicon and basic cations from the soil leaving the relatively insoluble iron and aluminum compounds.

A difference in the ratio of secondary minerals present in two soils with the same parent material indicates a difference in weathering intensity. As a soil becomes more intensely weathered, minerals with a ratio of two silicon tetrahedral sheets to one aluminum octahedral sheet (2:1) are converted to 1:1 minerals (one tetrahedral to one octahedral sheet). Still greater weathering converts 1:1 minerals to sesquioxides. Table 1 shows the sequence of clay mineral distribution as weathering increases.

Table 1 — Prominent minerals in soil clay fraction by relative degree of soil development from least developed (1) to most developed (13) (adapted from Jackson and Sherman 1953).

Gypsum, sulfides, and soluble salts	1
Calcite, dolomite, and apatite	2
Olivine, amphiboles, and pyroxenes	3
Micas and chlorite	4
Feldspars	5
Quartz	6
Muscovite	7
Vermiculite and hydrous micas	8
Montmorillonites	9
Kaolinite and halloysite	10
Gibbsite and allophane	11
Goethite, limonite, and hematite	12
Titanium oxides, zircon, and corundum	13

BUILDING A SOIL

Soil formation is a dynamic process with material continually added, transformed, and/or removed. Beginning with soil from a relatively uniform parent material, windblown sediments and annual floods, for example, add new material to the surface. Physically weathered saprolite adds material to the bottom of the profile. Dissolved and suspended material can be deposited or redistributed within a soil profile by water flowing below the surface. Evaporite minerals commonly accumulate in the subsoil at the top of a water table. Developmentally, a high annual sediment input often characterizes young soils.

At the other extreme, material is continually removed from a soil. Erosion by wind and water, even under dense vegetation, can remove five tons of soil per acre, per year. Whenever precipitation exceeds the field capacity of a soil, material can be leached below the soil solum (the root zone or an area active in soil pedogenesis). Biochemical degradation can remove organic matter. This can lead to a significant reduction in soil volume.

Changes also occur within a soil profile. Material is converted from one form to another and translocated within a profile. Clay, organic matter, and iron/aluminum ions typically migrate out from surface horizons especially in humid-region soils. The root zone provides a good environment for biogeochemical activity. Two examples of this are melanization and gleization. Melanization is the darkening of a soil layer by organic matter. This process gives the surface (A horizon) its brownish color. Gleization is the reduction of mostly iron-bearing minerals. It produces a gray to greenish color in soil. Saturation of a soil layer for long periods within a year usually causes this condition.

SOIL PHYSICAL PROPERTIES

Soils are categorized by certain physical and chemical characteristics. Many physical characteristics, including color, texture, and structure, can be determined in the field through careful observation and hand manipulations. Others, such as bulk density, require simple laboratory procedures.

COLOR

The most obvious soil characteristic is color. Although color is not used as a quantitative measure, it does give a good indication of certain conditions. A black to dark brown color usually suggests staining with organic matter. Red indicates the presence of oxidized iron and is normally found in well-drained soils. In soil saturated for long periods during a year, oxides become reduced, yielding a gray or bluish gray color. Soil color is described by three attributes: hue, value, and chroma.

Hue
Hue is the dominant spectral color. It is related to the wavelength of light reflected by soil particles. Common soil colors are white, gray, black, yellow, brown, red, and their various mixtures.

Value
Value is the lightness or darkness of the color. It is a measure of the amount of light reflected. Since moisture affects how light is reflected, normally soil color determinations are reported at three different moisture contents.

Chroma
Chroma is the strength or purity of color. It indicates the degree of difference between white, black, or neutral color.

■■■

Munsell Soil Color Charts
Soil color is characterized by comparison to the *Munsell Soil Color Charts*, which contain several series of distinctively colored chips (Figure 2). Each page represents a different hue. The Munsell book normally has 15 pages, each with a number (10, 7.5, 5, or 2.5) followed by a letter or letters indicating red (R), yellow (Y), green (G), blue (B), or combinations of these. For example, the 10 Y/R page contains color chips yellow-red (Y/R) with more yellow than red (10).

Value units range between 0 and 10. The numbers ascend vertically on the page from the lowest to highest numbers, indicating dark to light values. Thus, a 0 value is black with no light reflected, while 10 is white with maximum light reflected. Chroma units are arranged horizontally across the page from 0 to 10, increasing in numbers from left to right. Low numbers indicate an increase in grayness, while high numbers signify a pure color with little mixing with other hues. Hence, a designation of 10R 6/4 indicates a hue of 10R, a value of 6, and a chroma of 4.

On careful observation, most soils contain more than one color. Therefore, the matrix or dominant background color and mottles or colors different from the background must be described. While the matrix is simply described by a Munsell number, the mottles must be described by their abundance, size, and contrast to the background.

- *Abundance*
  Abundance is the relative amount of mottling. It is described by three classes. Mottles that occupy less than 2 percent of the exposed horizon are classified as *few*; 2 to 20 percent as *common*; and more than 20 percent as *many*.

- *Size*
  Size is a measure of the estimated average diameter of individual mottles along their greatest dimension. Mottles less than 5 mm in diameter are classified as *fine*; 5 to 15 mm as *medium*; and greater than 15 mm as *coarse*.

- *Contrast*
  Contrast is an indication of the relative difference in color between the matrix and mottles. If the contrast in color is only recognizable after close
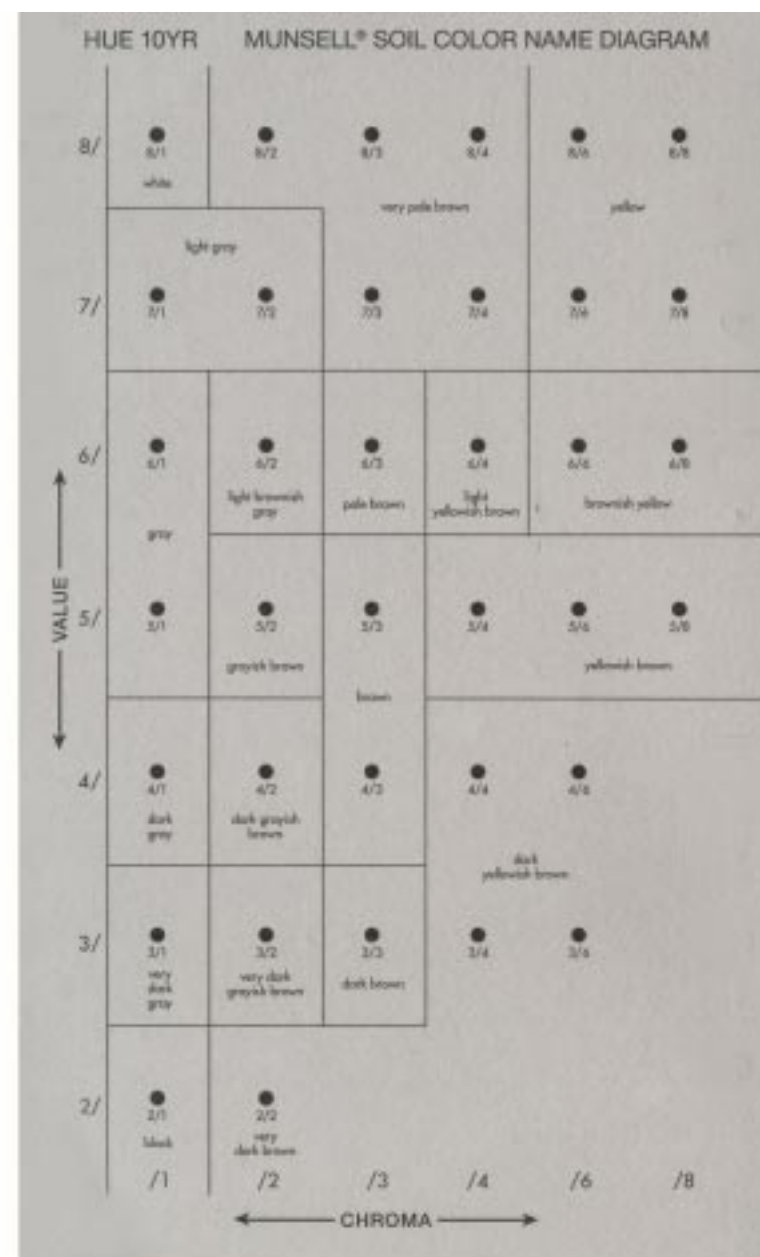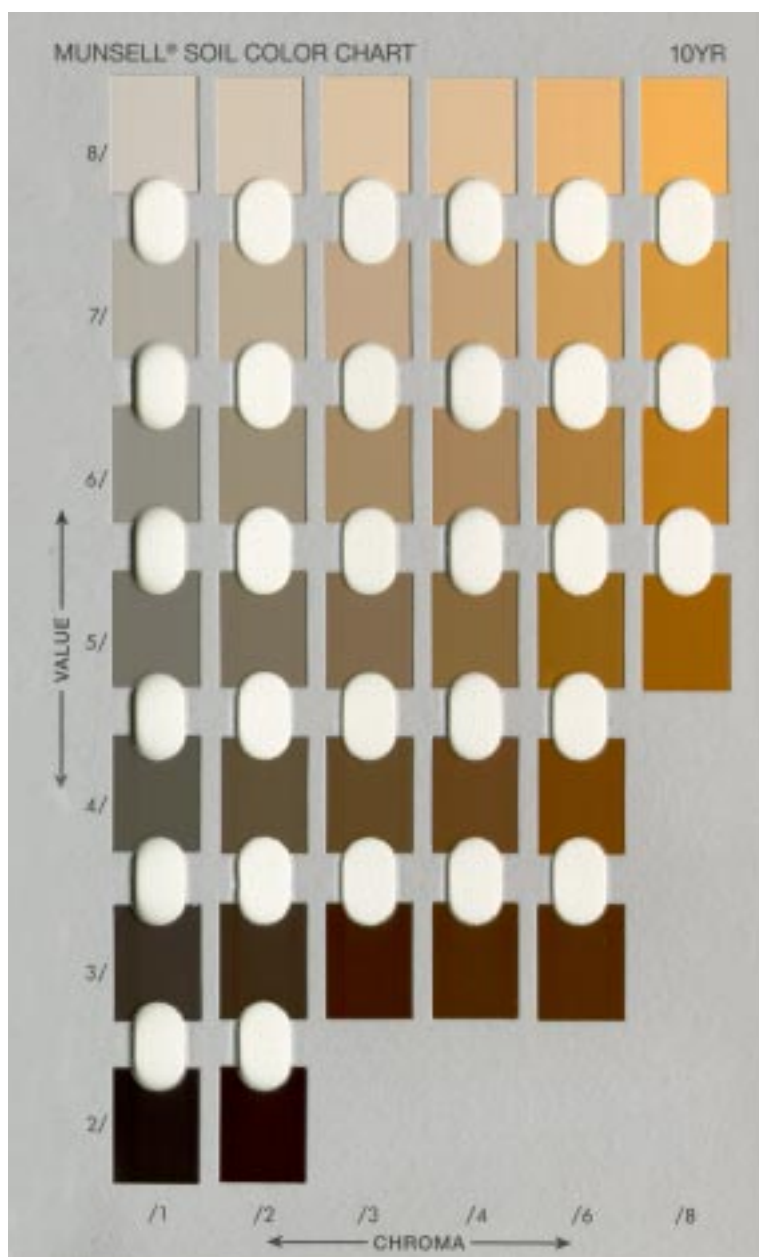
Figure 2 — Example pages from Munsell color charts. (For illustrative purposes only. Colors should not be used for soil comparisons.)

examination, it is classified as *faint*. A distinct pattern is readily seen although not striking. It may vary one or two hues or several value or chroma units. Mottles are considered *prominent* when they are the outstanding feature of the horizon. The colors of the matrix and mottles are separated by several units of hue, value, and chroma.

TEXTURE

Texture is the relative percentages of sand-, silt-, and clay-sized particles in a soil. It is a soil's single most influential physical property. Texture influences soil permeability, water infiltration rate, porosity, and fertility. Soil particles are classified into one of three groups based on size (diameter): clay (<0.002 mm); silt (0.002 to 0.05 mm); and sand (>0.05 mm) (Figure 3). In addition, larger objects may be described as pebbles (2 to 75 mm); cobbles (75 to 250 mm); stones (250 to 600 mm); and boulders (>600 mm).

These soil particle size boundaries are not totally arbitrary, as they roughly match changes in properties associated with the differing size fractions. Chemically, sand- and silt-sized particles are relatively inert. They differ in that sand is large enough to resist erosion by wind. Sand-sized particles are predominantly quartz (SiO_2) with small amounts of silicate-based primary minerals. Feldspars, hornblende, and micas may total up to 20 percent of the sand fraction in soil. Sand tends to have angular rough surfaces, whereas silt is spherical and more polished. Silt also is predominantly quartz with slightly larger amounts of primary minerals and iron and aluminum oxides. Wind easily erodes the smaller silt grains.

Clay particles are chemically active and stick together in aggregates that resist wind erosion and increase soil porosity. The clay fraction in most temperate region soils is dominated by layer aluminosilicate minerals. In the humid tropics, where weathering is more intense, iron and aluminum oxides and hydrous oxides are the dominant minerals present.

The USDA has specified twelve different textural classes of soil based on particle-size distribution. The textural class can be determined with any two particle size groupings. For example, using the triangle illustrated in Figure 4, the classification of a soil with 30 percent clay and 10 percent silt would be determined in the following way:

1. Find the mark labeled 30 on the left side of the triangle, which indicates the percent of clay.

2. Find the mark labeled 10 on the right side of the triangle, which indicates the percent of silt.

3. Trace a line from the left mark (clay) horizontally and from the right mark (silt) diagonally downward until the two lines intersect. The point of intersection indicates that the soil classification is "Sandy Clay Loam."

Note that if a line is drawn diagonally upward from the mark labeled 60 at the bottom of the triangle, which indicates the percent of sand, it will also intersect with the other two lines in the area labeled "Sandy Clay Loam." Hence the classification could also have been determined with the percents of clay and sand, or sand and silt.

The triangle in Figure 5 illustrates the relationship of texture and size, which is further explained in the following paragraphs.

Sand
Sand is the largest textural class. Sandy soils are dominated by the properties of sand: weak structure, rapid infiltration rate, slight erosion potential, loose consistence, and low fertility. When the soil is moist

CLAY	SILT	SAND					GRAVEL
		Very Fine	Fine	Medium	Coarse	Very Coarse	
0.002	0.05	0.1	0.25	0.5	1.0	2.0	

Figure 3 — Classification of soil particles by size (mm).
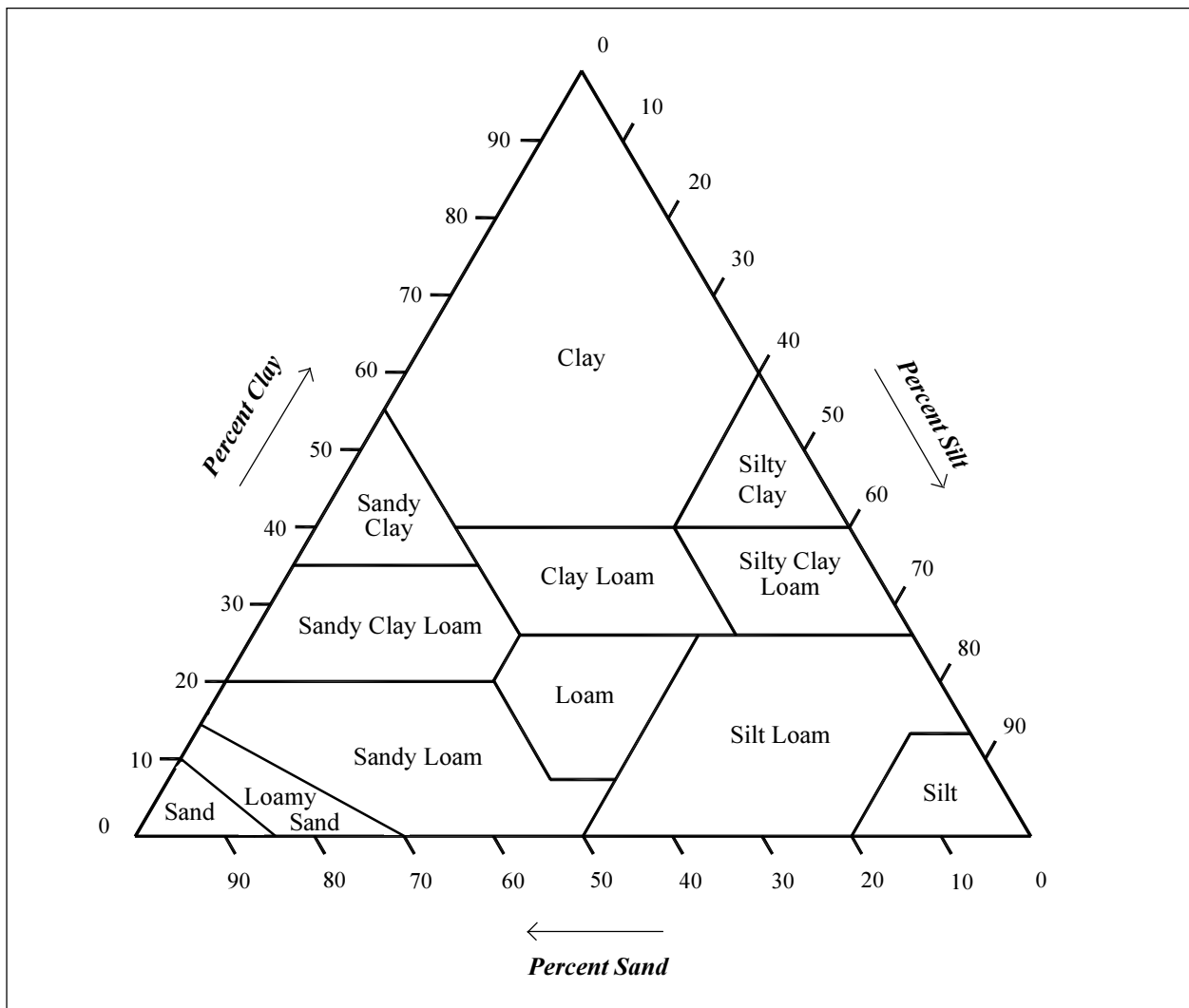
Figure 4 — Textural triangle illustrating the twelve USDA soil classifications.

and molded into a ball, it will easily crumble when touched (Figure 6). Sands contain 85 to 100 percent sand, 0 to 15 percent silt, and 0 to 10 percent clay. Sand is further divided into the following four categories.

- *Coarse Sand*
  More than 25 percent of sand particles are 0.50 mm diameter in size or larger, and less than 50 percent are between 0.05 and 0.50 mm.

- *Medium Sand*
  Twenty-five percent of the particles are larger than 0.25 mm. Less than 50 percent measure between 0.25 and 0.05 mm.

- *Fine Sand*
  More than 50 percent of the particles are between 0.10 and 0.25 mm or less than 25 percent are greater than 0.25 mm and less than 50 percent range between 0.05 and 0.10 mm.

- *Very Fine Sand*
  More than 50 percent of the particles are between 0.10 and 0.05 mm.

Loamy Sand
This category contains 70 to 85 percent sand, 0 to 30 percent silt, and 10 to 15 percent clay. Because loamy sand contains more clay than does sand, it is slightly cohesive and can be molded into a ball that
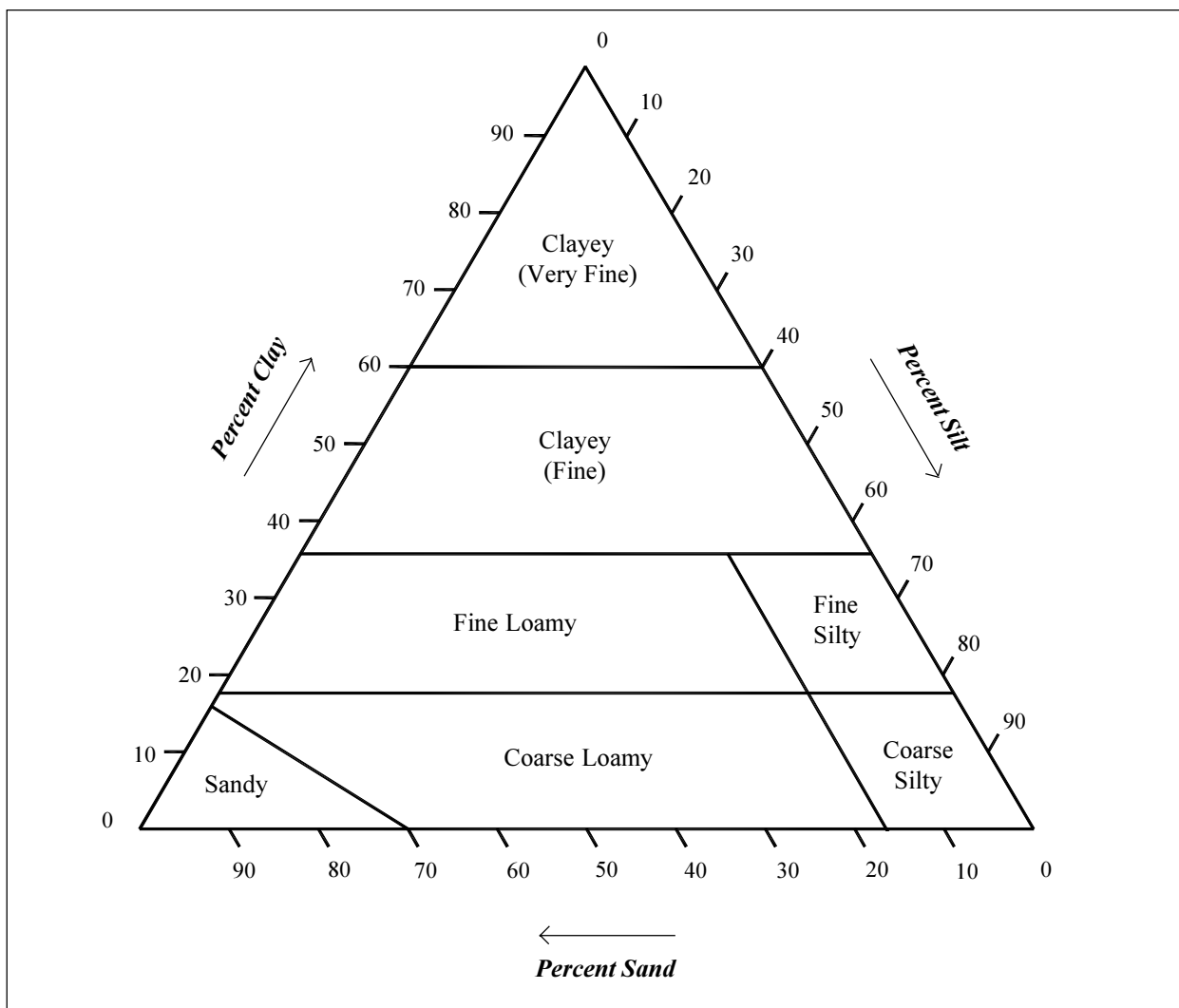
Figure 5— Textural triangle indicating the relationship of texture and size.

will maintain its form under gentle pressure. Soil squeezed between the thumb and forefinger, however, will not form a ribbon (Figure 6).

Silt

Silts are highly erodible, relatively infertile soils. They contain 80 to 100 percent silt, 0 to 20 percent sand, and 12 percent or less clay. They can be molded into a ball that keeps its shape under gentle pressure. The low percentage of clay precludes the formation of a ribbon. Silts are distinguished from loamy sands by placing a small amount of excessively wet material in the palm of your hand and rubbing the wet soil. Silt feels floury, whereas loamy sand feels gritty (Figure 6).

Clay

Clayey soils have a very slow infiltration rate, drain slowly, are very sticky and plastic when wet, and form hard clods when dry (Figure 6).

- *Clay*
  These soils contain 40 to 100 percent clay, 0 to 45 percent sand, and 0 to 40 percent silt. The high clay content makes these soils extremely sticky and plastic. They are readily shaped and, when molded, resist deformation if squeezed with moderate pressure. Pressure between the thumb and forefinger will create a ribbon longer than 5 cm. Clay feels non-gritty but not very slippery when excessively wet.

Figure 6 — Texture-by-feel flow chart.

- *Silty Clay*
  Silty clays are similar to clays. They contain 40 to 60 percent clay, 0 to 20 percent sand, and 40 to 60 percent silt. They form a ribbon greater than 5 cm in length and are very smooth when excessively wet.
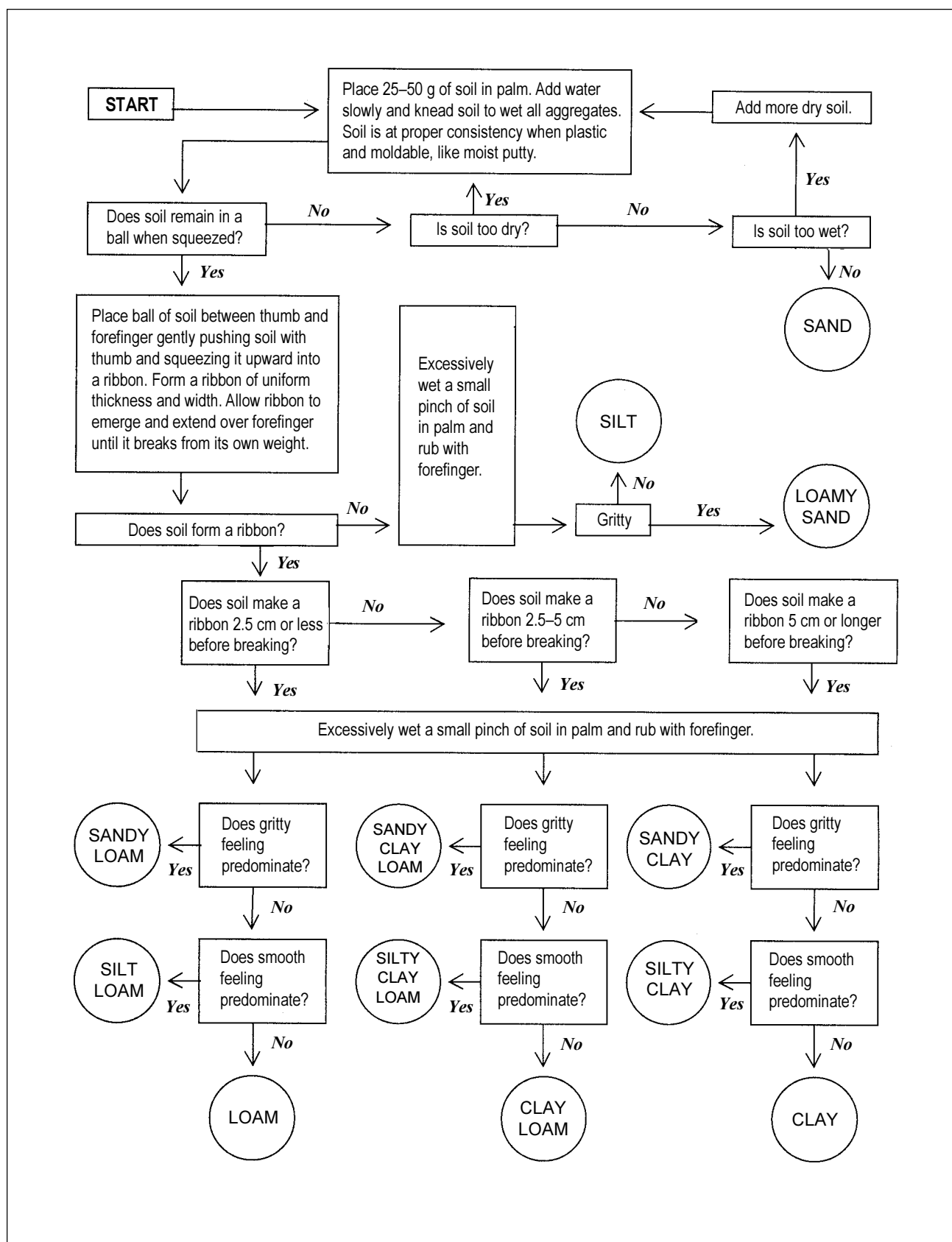
- *Sandy Clay*
  This category contains 35 to 55 percent clay, 45 to 65 percent sand, and 0 to 20 percent silt. Like the other clayey soils, sandy clays form long ribbons. When excessively wet, however, the higher sand content gives them a gritty feel.

Loam

Loamy soils have characteristics intermediate between those of sandy and clayey soils. These soils can be molded, and, as clay content increases, the mold becomes firm and resists deformation under moderate to strong hand pressure. Also, as the clay content increases, the infiltration rate slows and the soil forms hard clods when dry (Figure 6).

- *Sandy Loam*
  These loams contain 85 to 43 percent sand, 0 to 50 percent silt, and 0 to 20 percent clay. They are slightly cohesive and can form ribbons less than 2.5 cm in length. When wet, they have a very gritty feel. Sandy loams are further divided into the following categories:

  – *Coarse Sandy Loam*
    This group contains more than 25 percent sand-sized particles greater than 0.50 mm in diameter and less than 50 percent between 0.05 and 0.50 mm.

  – *Medium Sandy Loam*
    More than 30 percent of this group is made of particles greater than 0.25 mm in diameter; less than 25 percent measures between 1 and 2 mm; and less than 30 percent falls between 0.05 and 0.25 mm.

  – *Fine Sandy Loam*
    More than 30 percent of the fine sandy loams have particles that range in size between 0.05 and 0.10 mm; 15 to 30 percent are greater than 0.25 mm.

  – *Very Fine Sandy Loam*
    More than 30 percent of these loam particles range between 0.05 and 0.10 mm in diameter or more than 40 percent range between 0.05 and 0.25 mm (half of which are less than 0.10 mm) and less than 15 percent are greater than 0.25 mm.

- *Silt Loam*
  Silt loams contain 0 to 50 percent sand, 50 to 88 percent silt, and 0 to 27 percent clay. They are slightly cohesive when wet and form soft clods when dry. Silt loams feel smooth when wet and can form a ribbon less than 2.5 cm in length.

- *Loam*
  Loams contain 23 to 52 percent sand, 28 to 50 percent silt, and 7 to 27 percent clay. Slightly cohesive, they form ribbons less than 2.5 cm long, and feel moderately smooth when wet.

- *Sandy Clay Loam*
  Containing 45 to 80 percent sand, 0 to 28 percent silt, and 20 to 35 percent clay, these loams are moderately cohesive, forming ribbons between 2.5 and 5.0 cm in length. When wet, they have a gritty feel.

- *Silty Clay Loam*
  This group contains 0 to 20 percent sand, 60 to 73 percent silt, and 27 to 40 percent clay. Ribbons 2.5 to 5.0 cm long can be formed. When wet, the soil has a moderately gritty feel.

- *Clay Loam*
  Clay loams contain 20 to 45 percent sand, 15 to 53 percent silt, and 27 to 40 percent clay. These soils are sticky and plastic when wet and hard when dry. They form ribbons 2.5 to 5.0 cm in length and are moderately gritty when wet.

STRUCTURE

Soil structure is the aggregation of primary particles into secondary shapes or forms called peds. Shrink/swell, freeze/thaw, and other forces in soil bring particles into close proximity, where they can be cemented together. Organic matter forms a weak ce-

menting agent that may eventually give way to stronger bonding by humus. Silica, metal oxides, and carbonates also cement peds. Structure is described by grade, class, and type.

Grade

Grade represents the stability or distinctiveness of the ped. Because it is moisture dependent, the grade is normally described when the soil is slightly moist. Structural grades are classified as follows:

- *Weak*
  Peds can be seen in place with careful observation, however, they cannot be removed intact.

- *Moderate*
  Peds can be readily seen in place and, once removed, will remain intact with gentle handling.

- *Strong*
  Peds are distinctive in place and will withstand considerable handling.

Class

Class refers to the size of the ped. Since some structural types are inherently larger than others, a size range for each structural type has been determined, as illustrated in Table 2. The class designations are: very fine or very thin, fine or thin, medium, coarse

Table 2 — Types and classes of soil structure (Soil Conservation Service 1975).

CLASS	TYPE (SHAPE AND ARRANGEMENT OF PEDS)						
	Platelike, with one dimension (the vertical) limited and greatly less that the other two; arranged around a horizontal plane; faces mostly horizontal	**Prismlike**, with two dimensions (the horizontal) limited and considerably less than the vertical; arranged around a vertical line; vertical faces well defined; vertices angular		**Blocklike**; polyhedronlike, or spheroids, with three dimensions of the same order of magnitude, arranged around a point.			
				Blocklike; blocks or polyhedrons having plane or curved surfaces that are casts of the molds formed by the faces of the surrounding peds		Spheroids or polyhedrons having plane or curved surfaces, which have slight or no accommodation to the faces of surrounding peds	
		Without rounded caps	With rounded caps	Faces flattened; most vertices sharply angular	Mixed rounded and flattened faces with many rounded vertices	Relatively nonporous peds	Porous peds
	Platy	*Prismatic*	*Columnar*	*(Angular) Blocky*	*(Subangular) Blocky*	*Granular*	*Crumb*
Very fine or very thin	Very thin; <1 mm	Very fine; <10 mm	Very fine; <10 mm	Very fine; <5 mm	Very fine; <5 mm	Very fine; <1 mm	Very fine; <1 mm
Fine or thin	Thin; 1–2 mm	Fine; 10–20 mm	Fine; 10–20 mm	Fine; 5–10 mm	Fine; 5–10 mm	Fine; 1–2 mm	Fine; 1–2 mm
Medium	Medium; 2–5 mm	Medium; 20–50 mm	Medium; 20–50 mm	Medium; 10–20 mm	Medium; 10–20 mm	Medium; 2–5 mm	Medium; 2–5 mm
Coarse or thick	Thick; 5–10 mm	Coarse; 50–100 mm	Coarse; 50–100 mm	Coarse; 20–50 mm	Coarse; 20–50 mm	Coarse; 5–10 mm	—
Very coarse or very thick	Very thick; >10 mm	Very coarse; >100 mm	Very coarse; >100 mm	Very coarse; >50 mm	Very coarse; >50 mm	Very coarse; >10 mm	—

or thick, and very coarse or very thick. These range, respectively, from the smallest to the largest ped size for each type.

Type

Type refers to the shape of an individual ped (Table 2). Structural types are classified as follows:

- *Single Grain*
  Individual soil particles do not form aggregates; soil tends to have a sandy texture very low in organic matter.

- *Granular*
  These spheroids or polyhedrons are of roughly equal size in all dimensions and have plane or curved surfaces with slight or no accommodation to the faces of surrounding peds. Nonporous peds are generally found in sandy, low-organic-matter soils.

- *Crumb*
  These soil particles are similar to the granular class, however, the peds are porous.

- *Platy*
  These particles are much longer and wider than tall. The flat peds are arranged around a horizontal plane.

- *Angular Blocky*
  Angular blocky peds are of roughly equal size in all dimensions; blocks or polyhedrons have plane or curved surfaces that are casts of the molds formed by the faces of the surrounding peds. Faces are flattened, and most vertices are sharply angular. These particles tend to occur in B horizons or where moderate amounts of clay are present.

- *Subangular Blocky*
  Basically the same as the angular blocky particles, the subangular blocky faces are mixed, rounded, and flattened with many rounded vertices.

- *Prismatic*
  These particles, with two horizontal dimensions, are smaller than the vertical and taller than long or wide. They are arranged around a vertical line with vertical faces well defined and angular vertices without rounded caps. They are generally found in arid regions below the surface in horizons with moderate to high clay content.

- *Columnar*
  Columnar particles are like the prismatic particles but with rounded caps.

- *Massive or Structureless*
  The shape of these particles cannot be determined; they cling together in huge masses with no definite arrangement along lines of weakness. They are normally very hard.

BULK DENSITY

Bulk density is a measure of a soil's compactness, defined as a soil's oven-dry mass divided by its volume including the pore space. Soil is sampled by driving a metal cylinder of known volume into the soil. The cylinder is removed with a soil core intact. With a straight edge, the soil is leveled to the edges of the cylinder. In the lab, the intact core is oven dried at 100 ºC until there is no more weight change with additional drying. The oven-dry weight is determined and divided by the cylinder's volume.

The bulk density of soil in good physical condition ranges from 0.8 to 1.6 g cm^{-3}. Roots tend to proliferate more in soil with low bulk density. Soil with high organic matter content tends to have good structure and lower bulk density than similar soil with low organic matter. Cultivation destroys structure, reducing organic matter and increasing bulk density.

MICROMORPHOLOGY

Soil micromorphology is the study of size, shape, aggregation, etching, coating, accumulation, and depletion of minerals associated with various soil processes. Soil formation is a dynamic process with material continually being added, removed, and transformed. For example, water moving through a soil profile will pick up fine-textured material and deposit it as a coating along channels formed by the faces of adjacent peds.

Human activity can interrupt these processes and result in subtle differences in morphology. Water infiltration in the soil around a structure would be less than that in adjacent soil, because the structure would divert water away from it and compact the soil beneath it. Consequently, coatings on soil peds beneath the structure would be thinner, less well oriented, and have a different ratio of fine to coarse material than in the adjacent undisturbed soil.

CHEMICAL PROPERTIES OF SOIL

Soil minerals and organic matter have weak electrostatic charge sites associated with their surface. While these sites may be positively or negatively charged, the predominant charge is negative. The magnitude of the charge associated with clay minerals may be very large. Thus, soils with a high clay content tend to have a larger negative charge. This charge attracts cations dissolved in soil solution. A soil's capability to replace cations on the surface with those in a soil solution at a given pH is called cation exchange capacity (CEC). We report CEC in centimoles of charge per kilogram of soil ($cmol_c$ kg^{-1} soil). Exchange occurs on a charge-for-charge basis.

While the total amount of exchange depends on charge, a cation's affinity for the surface is a function of its charge and hydrated radius. Cations with a high charge and small hydrated radius have a greater affinity for the surface. The attraction to the surface of cations commonly found in soil solution is in the order of $Al^{3+}>Ca^{2+}>Mg^{2+}>K^+\sim NH_4^+>Na^+$. Because human habitation often selectively enriches or depletes ions, a comparison of ion ratios may help explain land-use patterns.

In soil classification it is helpful to know the proportion of a soil's CEC occupied by basic and acidic cations. Basic cations are Ca^{2+}, Mg^{2+}, K^+, and Na^+. The sum of these four basic cations divided by the CEC is called the percent base saturation. The ratio of Ca^{2+} to Mg^{2+} is an indication of the degree of weathering. The relative depletion of Ca^{2+} versus Mg^{2+} is an indication of advanced weathering. Exchange acidity is a term given to the sum of Al^{3+} and H^+ extracted in solution buffered at pH 8.2. Exchangeable acidity increases with leaching of basic cations and weathering.

Soil pH is a measure of the ability of soil minerals and organic matter to act as dilute acids and donate hydrogen ions into solution. A soil pH of <3.5 is normally associated with sulfur oxidation. This is common in coastal marshes and mine spoils, where buried sulfide minerals are exposed to oxygen. In forest soils, the acid-forming litter tends to keep soil pH below 5.5. Soil pH between 3.5 and 6.5 indicates free iron at the lower pH levels, and then aluminum hydrolysis at higher values controls pH. At pH values between 6.5 and 8.5, free $CaCO_3$ controls pH. Soil pH >8.5 indicates a high sodium content. These soils tend to be hard and very impermeable.

Soil organic matter is the partially decomposed residue of plants and animals. As it breaks down, it

coats soil particles giving them a dark brown to black color. Organic matter can be categorized into three fractions:

1. *Plant litter and animal remains*
   These tend to be new additions to the soil. Depending on the climate, they decay relatively quickly, with a turnover time of some five years or less.

2. *Microbial metabolites and stable cellular debris*
   This fraction includes humus, which gives soil many beneficial characteristics. It has a turnover time of fifty years or more. Table 3 details some of the effects humus has on soil.

3. *Highly resistant fraction*
   These compounds may last in soil for 2,500 years or longer.

Organic matter is strongly adsorbed by certain clay minerals. Organomineral complexes protect substance from microbial decay. As a result, soil organic matter stabilizes quickly—100 years in soils with a high clay content, and it may not reach a steady state in sandy soils for 1,500 years or more. With time, substances become increasingly decomposed, and the carbon to nitrogen ratio of soil organic matter increases.

Organic matter accumulates near the surface where there is a high root density (A horizon). Various vegetation types have different effects on soil organic matter. Grasslands have a dense rooting pattern resulting in a thick dark colored A horizon. Forest soils have a thinner layer of organic staining. In areas of high rainfall, soluble organic matter can be washed out of a subsurface horizon (E horizon). It accumulates in a lower horizon and appears as a dark staining on particles.

Table 3 — General properties of humus and associated effects in the soil (after Stevenson 1982).

PROPERTIES	REMARKS	EFFECTS ON SOIL
Color	Typical dark color of many soils is caused by organic matter	May facilitate warming
Water retention	Organic matter can hold up to 20 times its weight in water	Helps prevent drying and shrinking; improves moisture retention in sandy soils
Combination with clay minerals	Joins soil particles into structural units called aggregates	Permits gas exchange; stabilizes structure; increases permeability
Chelation	Forms stable complexes with Cu^{2+}, Zn^{2+}, Mn^{2+}, and other polyvalent cations	Buffers the availability of trace elements to plants
Solubility in water	Insolubility of organic matter results partially from its association with clay; salts of divalent and trivalent cations with organic matter are insoluble; isolated organic matter is partly soluble in water	Little organic matter is lost by leaching
pH relations	Organic matter buffers soil pH in the slightly acid, neutral, and alkaline ranges	Helps maintain a uniform pH in soil
Cation exchange	Total acidities of isolated fractions of humus range from 3,000 to 14,000 mmol kg^{-1}	Increases the cation exchange capacity (CEC) of the soil; 20 to 70 percent of the CEC of many soils is caused by organic matter
Mineralization	Decomposition of organic matter yields Co_2, NH_4^+, NO_3^-, PO_4^{3-}, and SO_4^{2-}	A source of nutrient elements for plant growth
Combination with organic molecules	Affects bioactivity, persistence, and biodegradability of pesticides	Modifies the application rate of pesticides for effective control

MASTER HORIZONS

Horizontal layers of soil called horizons can be described by their different morphological characteristics. Capital letters designate master horizons, which are further subdivided by Arabic numerals. Master horizons are used to describe similar appearing soil layers and should not be confused with diagnostic horizons used to classify soils.

O Horizon
The O horizon is a surface layer dominated by organic material. An O horizon may be found below the surface if it has been buried. Predominantly found in forested regions, the O horizon is composed of leaf litter in various stages of decay.

A Horizon
The A horizon is the uppermost mineral layer. It may lie below the O horizon. An A horizon has a high concentration of humus and is not dominated by the migration of clay, humus, aluminum, or iron into or out of the horizon. The humus content gives it a darker color than the horizon below.

E Horizon
The E horizon is a layer of eluviation where clay organic matter and iron and aluminum oxides have been leached out. Remaining material tends to be light colored and coarse textured. The E horizon is normally found below an O or an A horizon and above a B horizon. However, it may separate sections of a B horizon.

B Horizon
The B horizon is a subsurface layer showing evidence of one or more of the following processes:

1. illuvial accumulation of alumino-silicate clay, iron, aluminum, gypsum, or silica;

2. carbonate removal;

3. residual concentration of sesquioxides;

4. coating of sesquioxides, which makes the horizon conspicuously lower in color value, higher in chroma, or redder in hue without apparent illuviation of iron than that found in the overlying and underlying horizons;

5. alteration that forms silicate clay or liberates oxides, or both, and that forms a granular, blocky, or prismatic structure if volume changes accompany changes in moisture context; or

6. brittleness.

C Horizon
The C horizon is a layer of minimal alteration. Material may be similar to or unlike that from which the other horizons formed. C horizons lack the properties of O, A, E or B horizons, and can include coprogenous earth (sedimentary peat), diatomaceous earth, saprolite, unconsolidated bedrock, and other uncemented geologic materials or materials soft enough for excavation with moderate difficulty.

R Layer
An R layer refers to hard bedrock. Material is cemented and manual excavation is impossible. Intrusive soils can be found in rare cracks in the bedrock. Examples of R layer material include: granite, basalt, quartzite, indurated limestone, or sandstone.

TRANSITIONAL HORIZONS

Transitional horizons are dominated by properties of one master horizon but have the subordinate properties of another. These are designated by two capital letters, for example, AB, EB, BE, or BC. The first letter represents the dominant horizon characteristics, the second indicates the weaker expressed characteristics.

A second type of transitional horizon has two distinct parts with recognizable properties of the two master horizons indicated by the capital letters. Parts of one surround the other. This type of transitional

horizon is designated by a capital letter for the part with the greatest volume, followed by a slash and another capital letter for the secondary part (for example, E/B, B/E, or B/C).

SUBORDINATE DISTINCTIONS

Master horizons are further divided by subordinate characteristics, which usually do not apply to transitional horizons. Subordinate distinctions are identified by lower-case letters, called suffix symbols. In some cases, they describe an accumulation of material. This means that the so-designated horizons contain more of the material in question than is presumed to have been present in the parent material. For example, B_t refers to a B horizon with more clay than normal. The symbols and their meanings follow.

- *a — highly decomposed organic material*
  Used with O to indicate the most highly decomposed organic materials, which have rubbed fiber content of less than 17 percent of the volume.

- *b — buried genetic horizon*
  Used in mineral soils to indicate identifiable buried horizons with major genetic features that were developed before burial. Genetic horizons may or may not have formed in the overlying material, which may be either like or unlike the assumed parent material of the buried soil. This symbol is not used in organic soils or to separate an organic from a mineral layer.

- *c — concretions or nodules*
  Indicates a significant accumulation of concretions or nodules. Cementation is required, but the cementing agent is not specific, except that it cannot be silica. The symbol is not used if the concretions or nodules consist of dolomite or calcite, or more soluble salts. It is used if the nodules or concretions are enriched with minerals that contain iron aluminum, manganese, or titanium.

- *d — physical root restriction*
  Indicates root-restricting layers in naturally occurring or man-made unconsolidated sediments or materials, such as dense basal till, plow pans, and other mechanically compacted zones.

- *e — organic material of intermediate composition*
  Used with O to indicate organic materials of intermediate composition with rubbed fiber content between 17 and 40 percent (by volume).

- f — *frozen soil*
  Indicates permanent ice content in a horizon or layer. The symbol is not used for seasonally frozen layers or for so-called dry permafrost (material that is colder than 0° but does not contain ice).

- g — *strong gleying*
  Indicates either that iron has been reduced and removed during soil formation, or that saturation with stagnant water has preserved it in a reduced state. Most of the affected layers have a chroma of 2 or less, and many have redox concentrations. The low chroma can represent either the color of reduced iron or the color of uncoated sand and silt particles from which the iron has been removed. The symbol *g* is not used for materials of low chroma that have no history of wetness, such as some shales or E horizons. If g is used with B, pedogenic change in addition to gleying is implied. The horizon is designated Cg if no other pedogenic change besides gleying has occurred.

- h — *illuvial accumulation of organic matter*
  Used with B to indicate the accumulation of illuvial, amorphous, dispersible organic-matter-sesquioxide complexes if the sesquioxide component is dominated by aluminum but is present only in small quantities. The organo-sesquioxide material coats sand and silt particles. In some horizons, these coatings have coalesced, filled pores, and cemented the horizon. The symbol *h* is also used in combination with *s*, as in Bhs, if the amount of sesquioxide component is significant but the color value and chroma of the horizon when moist is 3 or less.

- i — *slightly decomposed organic matter*
  Used with O to indicate the least decomposed of the organic materials. Its rubbed fiber content is 40 percent or more (by volume).

- k — *accumulation of carbonates*
  Indicates an accumulation of alkaline-earth carbonates, commonly calcium carbonate.

- m — *cementation or induration*
  Indicates continuous or nearly continuous cementation. The symbol *m* is used for horizons that are more than 90 percent cemented, although they may be fractured. The cemented layer is physically root-restrictive. The predominant cementing agent (or the two dominant cementing agents) may be indicated by using defined letter suffixes, singly or in pairs. Following are some suffix combinations and what they indicate:

  km — cementation by carbonates;
  qm — cementation by silica;
  sm — cementation by iron;
  ym — cementation by gypsum;
  kqm — cementation by lime and silica; and
  zm — cementation by salts more soluble than
          gypsum.

- n — *accumulation of sodium*
  Indicates an accumulation of exchangeable sodium.

- o — *residual accumulation of sesquioxides*

- p — *tillage or other disturbance*
  Indicates a disturbance of the surface layer by mechanical means, pasturing, or similar uses. A disturbed organic horizon is designated Op. A disturbed mineral horizon is designated Ap, even though it is clearly a former E, B, or C horizon.

- q — *accumulation of silica*
  Indicates an accumulation of secondary silica.

- r — *weathered or soft bedrock*
  Used with C to indicate root-restrictive layers of saprolite, such as weathered igneous rock, or of soft bedrock, such as partly consolidated sandstone, siltstone, and shale. Excavation difficulty is low to high.

- s — *illuvial accumulation of sesquioxides and
      organic matter*
  Used with B to indicate an accumulation of illuvial, amorphous, dispersible, organic-matter-sesquioxide complexes if both organic-matter and sesquioxide components are significant, and if color value and chroma of the horizon when moist is 4 or more. The symbol is also used in combination with the symbol *h*, as in Bhs, if both the organic-matter and sesquioxide components are significant, and if the color value and chroma, moist, is 3 or less.

- ss — *presence of slickensides*
  Indicates the presence of slickensides. Slickensides result directly from the swelling of clay minerals and shear failure, commonly at angles of 20 to 60 degrees above horizontal. They are indicators that other vertic characteristics, such as wedge-shaped peds and surface cracks, may be present.

- t — *accumulation of silicate clay*
  Indicates an accumulation of silicate clay that has either formed and subsequently been translocated within the horizon or has been moved into the horizon by illuviation, or both. At least some part of the horizon should show evidence of clay accumulation either as coatings on surfaces of peds or in pores, or as lamellae or bridges between mineral grains.

- v — *plinthite*
  Indicates the presence of iron-rich humus-poor reddish material that is firm or very firm when moist and hardens irreversibly when exposed to the atmosphere and to repeated wetting and drying.

- w — *development of color or structure*
  Used with B to indicate the development of color and structure, or both, with little or no apparent illuvial accumulation of material. It should not be used to indicate a transitional horizon.

- x — *fragipan character*
  Indicates a genetically developed layer with a combination of firmness, brittleness, and commonly a higher bulk density than adjacent layers. Some part of the layer is physically root-restrictive.

- y — *accumulation of gypsum*

- z — *accumulation of salts more soluble than gypsum*

DIAGNOSTIC HORIZONS: EPIPEDONS

Master horizons describe a soil profile, while diagnostic horizons are used to classify soils. Whereas master horizons are based on appearance, diagnostic horizons are based on soil formation processes. These two classification schemes are not complementary. Diagnostic horizons can contain all or part of more than one master horizon.

An epipedon is the surface, or uppermost soil horizon. It may be thinner than the soil profile A horizon, or include the E or part or all of the B horizon. Epipedons derived from bedrock lack rock structure and are normally darkened by organic matter.

Anthropic epipedon
While similar to the mollic epipedon, the anthropic epipedon contains greater than 250 ppm citric acid soluble P_2O_5 with or without a 50 percent base saturation and requires that the soil is moist three months or more over 8 to 10 years. It is commonly found in fields cultivated over long periods of time.

Histic epipedon
This organic horizon is water saturated long enough for reduced conditions to occur unless artificially drained. It is 20 to 60 cm thick and has a low bulk density often less than 1 g cm^{-3}. The actual organic matter content is dependent on the percent clay. If the soil has not been plowed, it must contain between 12 percent or more organic carbon with no clay and 18 percent or more organic carbon with 60 percent or more clay. When the soil has been plowed, the organic carbon content is from 8 percent with no clay to 16 percent with 60 percent or more clay.

Melanic epipedon
This thick, black surface horizon with a high organic matter content formed in volcanic ejecta. It has a minimum thickness of 30 cm, contains 6 percent or more organic carbon, and has volcanic mineral-like allophane throughout.

Mollic epipedon
This epipedon is a soft dark grassland soil. Its organic carbon content is 0.6 percent or more resulting in a color value of 3 or less moist, 5 or less dry. Its base saturation is 50 percent or more. It measures a minimum of 18 cm thick if not directly above

a petrocalcic horizon, duripan, or a lithic or paralithic contact, and contains less than 250 ppm P_2O_5. Moist three months or more each year, it cannot have both hard consistence and massive structure.

Ochric epipedon
This epipedon does not meet the definitions of any other surface horizon. It does not have the thickness, percent organic carbon, or color to be a mollic or umbric epipedon. The ochric epipedon extends to the first illuvial (B) horizon.

Plaggen epipedon
This man-made horizon is 50 cm or more thick and has resulted from centuries of accumulation of sod, straw, and manure, for example. It commonly contains artifacts such as pottery and bricks.

Umbric epipedon
Mollic-like in thickness, organic carbon content, color, P_2O_5 content, consistence, and structure, this epipedon has less than 50 percent base saturation.

DIAGNOSTIC SUBSURFACE HORIZONS

Diagnostic subsurface horizons can be categorized as weakly developed horizons, as horizons featuring an accumulation of clay, organic matter, or inorganic salts, as cemented horizons, or as strongly acidic horizons.

Agric
This horizon forms under a plow layer. It normally has lamellae (finger-shaped concentrations of material) of illuvial humus, silt, and clay.

Albic
Clay, humus, and other coatings have been leached from this eluvial horizon, leaving light-colored sand and silt particles.

Argillic
This illuvial horizon of mostly high-charged layer silicate clay has clay films on the faces of peds or some indication of clay movement. It is at least one-tenth the thickness of all overlying horizons. If the overlying horizon has less than 15 percent clay, the argillic has 3 percent more clay than the eluvial ho-

rizon above. If the overlying horizon has 15 to 40 percent clay, the argillic has 1.2 times that amount. If the overlying horizon has over 40 percent clay, the argillic has 8 percent more clay.

Calcic
Measuring 15 cm or more thick, this horizon is not indurated or cemented, and has evidence of calcium carbonate movement. It has a 15 percent or more $CaCO_3$ equivalent unless there is below 18 percent clay, then the requirement is a 5 percent or more $CaCO_3$ equivalent. If the horizon is cemented, it is classified as petrocalcic.

Cambic
This horizon shows some evidence of alterations but is very weakly developed between A and C horizons. The cambic horizon has less illuviation evidence than found in the argillic and spodic horizons.

Duripan
This subsurface horizon is cemented by silica in more than 50 percent of its volume. It dissolves in concentrated basic solution or alterating acid and then basic solutions, but does not slake in HCl.

Fragipan
A fragipan is a brittle horizon situated at some depth below an eluvial horizon. It has a low organic matter content, lower bulk density than overlying horizons, and hard or very hard consistence when dry.

Glossic
This transitional horizon has parts of an eluvial horizon and the remnants of a degrading argillic, kandic, or natric horizon.

Gypsic
An illuvial horizon, the gypsic is 15 cm or more thick with 5 percent or more gypsum and at least 1 percent by volume visible gypsum. If the horizon is cemented, it is classified as petrogypsic.

Kandic
The kandic is a horizon with an illuvial accumulation of 1:1 (kaolinite-like) clay that has a CEC of less than 16 $cmol_c$ kg^{-1} clay. A clay increase within 15 cm of the overlying horizon is 4 percent or more if the surface has less than 20 percent clay; 20 per-cent or more if the surface has 20 to 40 percent clay; or 8 percent or more if the surface has greater than 40 percent clay. The horizon is 30 cm thick unless there is a lithic, paralithic, or petroferric contact, in which case minimum thickness is 15 cm. Organic carbon constantly decreases with increasing depth.

Natric
The natric horizon is similar to the argillic horizon with the additional characteristics of columnar structure. It has an exchangeable sodium percentage of 15 percent or more.

Oxic
The oxic horizon contains highly weathered clays. It is 30 cm or more thick and has a CEC of less than 16 $cmol_c$ kg^{-1} clay. Less than 10 percent of the minerals are weatherable. Within a distance of 15 cm, there is an increase in clay of 4 percent or less if the surface horizon contains less than 20 percent clay; less than 20 percent if the surface contains 20 to 40 percent clay; or 8 percent or less if the surface contains 40 percent or more clay.

Placic
This subsurface horizon is cemented by iron, iron and manganese, or iron and organic matter.

Salic
Measuring 15 cm or more thick, the salic horizon contains at least 2 percent soluble salt. A 1:1 soil to water extract has an electrical conductivity of 30 dS/m^{-1} (decisiemens per meter) or more.

Sombric
The sombric horizon has an illuvial accumulation of humus that is not associated with aluminum (spodic) or sodium (natric).

Spodic
This illuvial horizon contains high pH dependent charge material. A sandy-textured horizon, it has an accumulation of humus with aluminum and/or iron.

Sulfuric
The sulfuric horizon forms as a result of draining soil with a high sulfide content that is oxidized to sulfates, drastically reducing the pH. It is at least 15 cm thick and has a pH of 3.5 or less.

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FIELD DESCRIPTION CHECK LIST

(Complete entry or circle/highlight appropriate description.)

MASTER HORIZON   O   A   E   B   C   R

SUBORDINATE DISTINCTION (a–z)   _____

DEPTH   from _____   to_____

SLOPE   _____ percent

COLOR   *Hue*   *Value/Chroma*

            Matrix   _____   _____

            Mottles   _____   _____

            Abundance   Few (<2 percent)   Common (2-20 percent)   Many (>20 percent)

            Size   Fine (<5 mm)   Medium (5-15 mm)   Coarse (>15 mm)

            Contrast   Faint (mottles recognizable with close examination)

                        Distinct (mottles readily seen but not striking; one or two hues or several value or chroma units apart)

                        Prominent (mottles an outstanding feature; hue, value, and chroma several units apart)

TEXTURE:

Dominant Feel When Wet	*Ribbon Size*			
	None	*Short (<1 in.)*	*Medium (1–2 in.)*	*Long (>2 in.)*
Smooth	Silt	Silt loam	Silty clay loam	Silty clay
Neither smooth nor gritty		Loam	Clay loam	Clay
Gritty (very slightly cohesive)	Loamy sand			
Gritty (noncohesive)	Sand	Sandy loam	Sandy clay loam	Sandy clay

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CONSISTENCE:

Moist:
- 0. Loose .... Soil material noncoherent
- 1. Very friable .... Aggregates crush easily
- 2. Friable .... Gentle pressure required to crush aggregates
- 3. Firm .... Moderate pressure required to crush aggregates
- 4. Very firm .... Strong pressure required to crush aggregates
- 5. Extremely firm ...... Aggregates cannot be crushed by hand

Dry:
- 0. Loose .... Soil material noncoherent
- 1. Soft .... Aggregates easily break to single grains
- 2. Slightly hard .... Gentle pressure required to crush material
- 3. Hard .... Aggregates barely breakable by thumb and finger
- 4. Very hard .... Aggregates barely breakable in both hands
- 5. Extremely hard ...... Aggregates cannot be broken by hand

ROOTS:

Abundance: Few (<2 percent)   Common (2–20 percent)   Many (>20 percent)

Size: Fine (<5 mm)   Medium (5–15 mm)   Coarse (>15 mm)

HORIZON BOUNDARY:

Thickness: Abrupt (<1 in.)   Clear (1–2.5 in.)   Gradual (2.5–5 in.)   Diffuse (>5 in.)

Shape: Smooth (boundary is nearly a plane)

Wavy (undulating, greater across the slope)

Irregular (undulating, greater in the direction of the slope)

Broken (discontinuous)